Energy Reconstruction in KamLAND

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KamLAND is a scintillating detector. It is composed of a steel sphere with an 18m diameter that contains a balloon filled with a mineral oil pseudo-cumene mixture which scintillates surrounded by a layer of plain mineral oil that does not. The sphere is instrumented with 1325 seventeen inch photomultiplier tubes (PMTs) and 554 twenty inch photo-multiplier tubes. Charged particles and gamma rays produce scintillation light in the balloon that is then absorbed and remitted at a longer wavelengths for the PMTs to detect. The time and charge of the photo-electron hits recorded by each PMT is used to reconstruct the original particles position and energy.

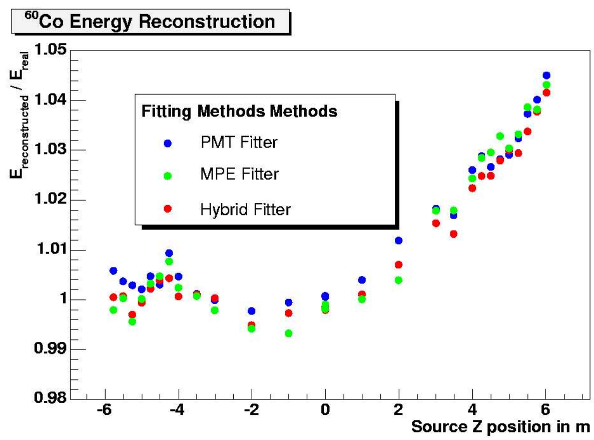

FIG. 1: Energy Reconstruction of ^{60}Co in Z

The current algorithm, PMT Fitter, uses a maximum likelihood fit to find the energy. The maximum likelihood is defined as the sum over the likelihood of each PMT being hit or not being hit in that particular event:

$$L(E,\vec{x}) = \prod_{i=1}^{1879} \begin{cases} 1-e^{-\mu_i} & \text{if hit} \\ e^{-\mu_i} & \text{if not hit} \end{cases} \qquad (1)$$

where μ_i is the expected number of photo-electrons for that PMT. The expected number of photo-electrons is the sum of the number of accidental photo-electrons δ_i and the number expected for that energy at that position:

$$\mu_i(E,\vec{x}) = \eta_i \frac{\frac{\Omega(r,\theta)}{4\pi} e^{-r/\Lambda}}{\frac{\Omega(r_{center},\theta_{center})}{4\pi} e^{-r_{center}/\Lambda}} * E + \delta_i \qquad (2)$$

where η_i is the number of photo-electrons per MeV at the center of the detector, Λ is the attenuation in both the scintillator and buffer oil, and Ω is the solid angle subtended by the PMT. The light propagation model above is very simple consisting of just the solid angle calculation and one exponential. The parameters that go into the fit, η_i and δ_i are extracted from ^{60}Co in the center of the detector.

This method of calculating energy saturates at approximately 5 MeV to get an accurate measure of higher energies it becomes necessary to count the number of photo-electrons each PMT detected. To count the number of photo-electrons detected a conversion from the amount of charge collected by the PMT to photo-electrons must be made. The probability of a PMT's charge being one photo-electron is calculated from ^{60}Co charge distributions. This probability, $P(q \mid n)$ is included in the likelihood calculation for the energy and PMTs are now separated by whether the amount of charge collected was above the electronics threshold q_o or not.

$$L(E,\vec{x}) = \prod_{i=1}^{1879} \begin{cases} \sum_{n=1}^{\inf} \frac{\mu_i^n e^{-\mu_i}}{n!} P(q \mid n) & \text{q} > q_o \\ e^{-\mu_i} + \sum_{n=1}^{\inf} \frac{\mu_i^n e^{-\mu_i}}{n!} \int_{-\inf}^{q_o} dq P(q \mid n) & \text{q} < q_o \end{cases} \qquad (3)$$

This method, MPE fitter, works well for the 17 inch PMTs but the poorer charge resolution of the 20 inch PMTs requires they continue to use the PMT fitter algorithm so a hybrid method was constructed in this way. At this time the method for calculating the solid angle was changed from an empirical formula to numerical integral over the PMT face, a correction for shadowing was added to the light model used in the calculation of μ_i, and a correction for busy channels was added. The current performance of the fitters along the z-axis is shown in Fig. 1 and indicates that these improvements in the model have uncovered a new position dependent energy bias. Studies of this bias are pointing to a new model for the propagation of light through the scintillator but more studies are still needed.